NOAA Technical Memorandum NESDIS NGDC-6

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Boulder, Colorado
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Digital Elevation Model of Savannah, Georgia: Procedures, Data Sources and Analysis

1. Introduction

In December 2006, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed a bathymetric–topographic digital elevation model (DEM) of Savannah, Georgia (Fig. 1) for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The 1/3 arc-second[1] coastal DEM will be used as input for the Method of Splitting Tsunami (MOST) model developed by PMEL to simulate tsunami generation, propagation and inundation. The DEM was generated from diverse digital datasets in the region (grid boundary and sources shown in Fig. 3) and will be used for tsunami inundation modeling, as part of the tsunami forecast system SIFT (Short-term Inundation Forecasting for Tsunamis) currently being developed by PMEL for the NOAA Tsunami Warning Centers. This report provides a summary of the data sources and methodology used in developing the Savannah DEM.

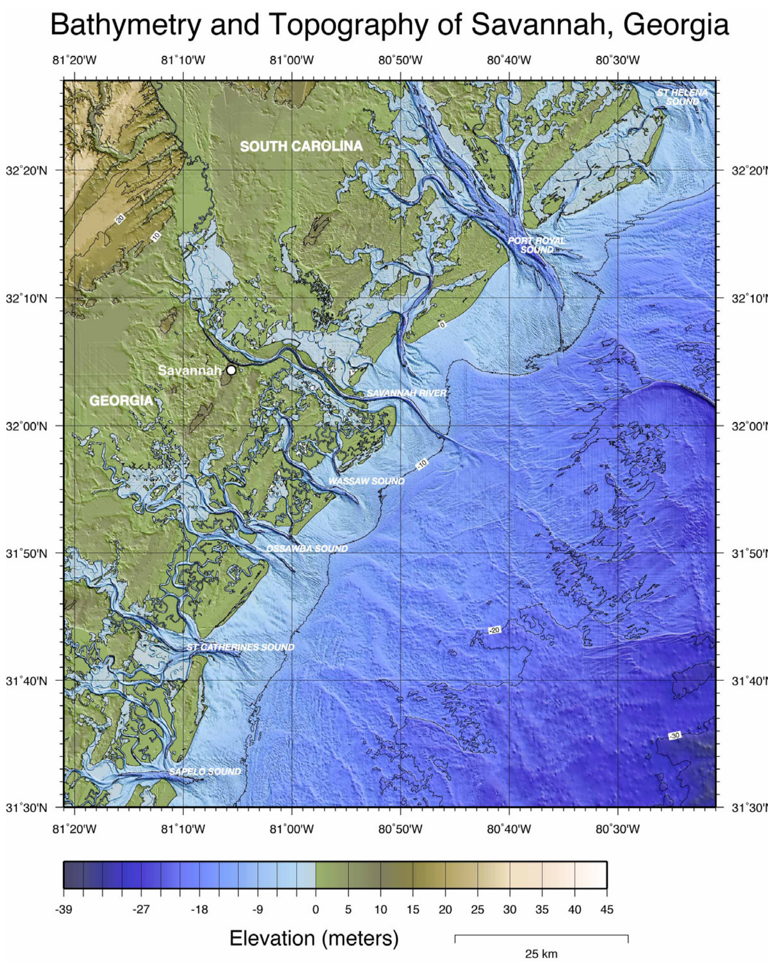

Figure 1. Shaded-relief image of the Savannah, Georgia region. Contour interval (referenced to Mean High Water): 10 meters.

1. The Savannah DEM is built upon a grid of cells that are square in geographic coordinates (latitude and longitude), however, the cells are not square when converted to projected coordinate systems, such as UTM zones (in meters). At the latitude of Savannah, Georgia (32°05′ N, 81°06′ W) 1/3 arc-second of latitude is equivalent to 10.27 meters; 1/3 arc-second of longitude equals 8.75 meters.

2. Study Area

The Savannah DEM covers the coastal area surrounding the Savannah River and includes the southern tip of South Carolina and easternmost Georgia. The region is characterized by barrier islands, tidal inlets, extensive sand shoals, and wide tidal marshlands. Barrier islands were formed by river deposition and by sea level fluctuation in the Pleistocene. The islands are generally level but include recently formed dunes, visible in LiDAR data and satellite imagery that can reach up to 50 feet above mean sea level (MSL). River inlets are characterized by sandy shoals formed as large sediment loads are deposited at the coast. Sediment deposition, alongshore currents, and wave action modify the shoreline seasonally.

Highly influenced by the tides, inland marshlands form a network of creeks, streams, and estuaries that are prone to seasonal and tidal flooding (Fig. 2). The marshlands have been influenced by deposition of sediment during periods of high sea level, and erosion during periods of lower sea level.

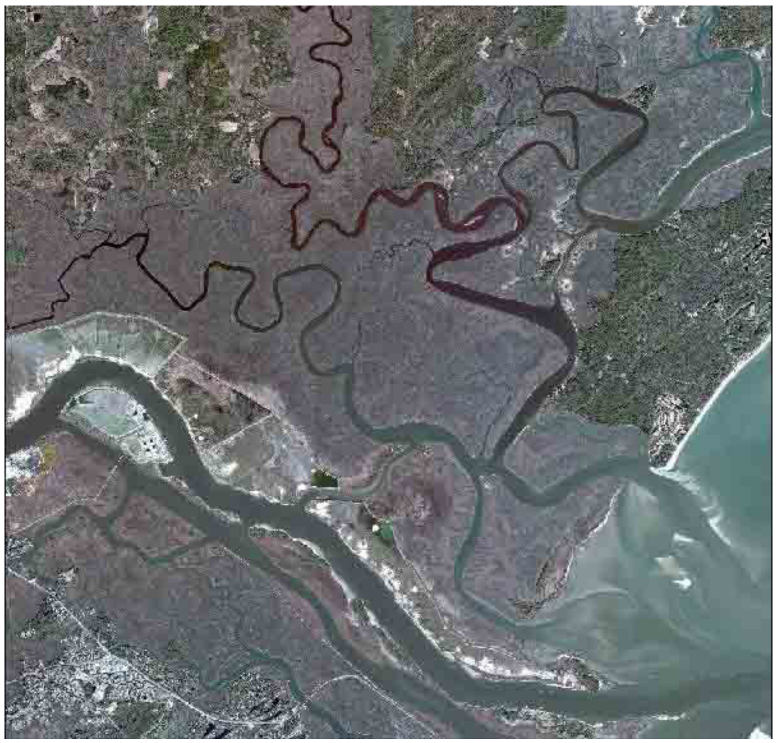

Figure 2. *Satellite image of the mouth of the Savannah River from DigitalGlobe.*

3. Methodology

The Savannah DEM was developed to meet PMEL specifications (Table 1), based on input requirements for the MOST inundation model. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: World Geodetic System 1984 (WGS84) and Mean High Water (MHW), for modeling of "worst-case scenario" flooding, respectively. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1. PMEL specifications for the Savannah DEM.

Grid Area	Savannah, Georgia
Coverage Area	81.35 º to 80.35º W; 31.5º to 32.45º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Grid Spacing	1/3 arc-second
Grid Format	ESRI ASCII raster grid

3.1 Data Sources and Processing

Shoreline, bathymetric, topographic and combined topographic–bathymetric digital datasets (Fig. 3) were obtained from several U.S. federal and state agencies, including: NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS), Coastal Services Center (CSC), National Geodetic Survey (NGS), and NGDC; the U.S. Geological Survey (USGS); the U.S Army Corps of Engineers (USACE); Chatham County, Georgia; and Beaufort County, South Carolina. Safe Software's (http://www.safe.com/) FME data translation tool package was used to shift datasets to WGS84 horizontal datum and to convert into ESRI (http://www.esri.com/) ArcGIS shape files. The shape files were then displayed with ArcGIS to assess data quality and manually edit datasets; NGDC's GEODAS software (http://www.ngdc.noaa.gov/mgg/geodas/) was used to manually edit large xyz datasets. Vertical datum transformations to MHW were also accomplished using FME, based upon data from the NOAA Savannah tidal station, as no VDatum model software (http://vdatum.noaa.gov/) was available for this area.

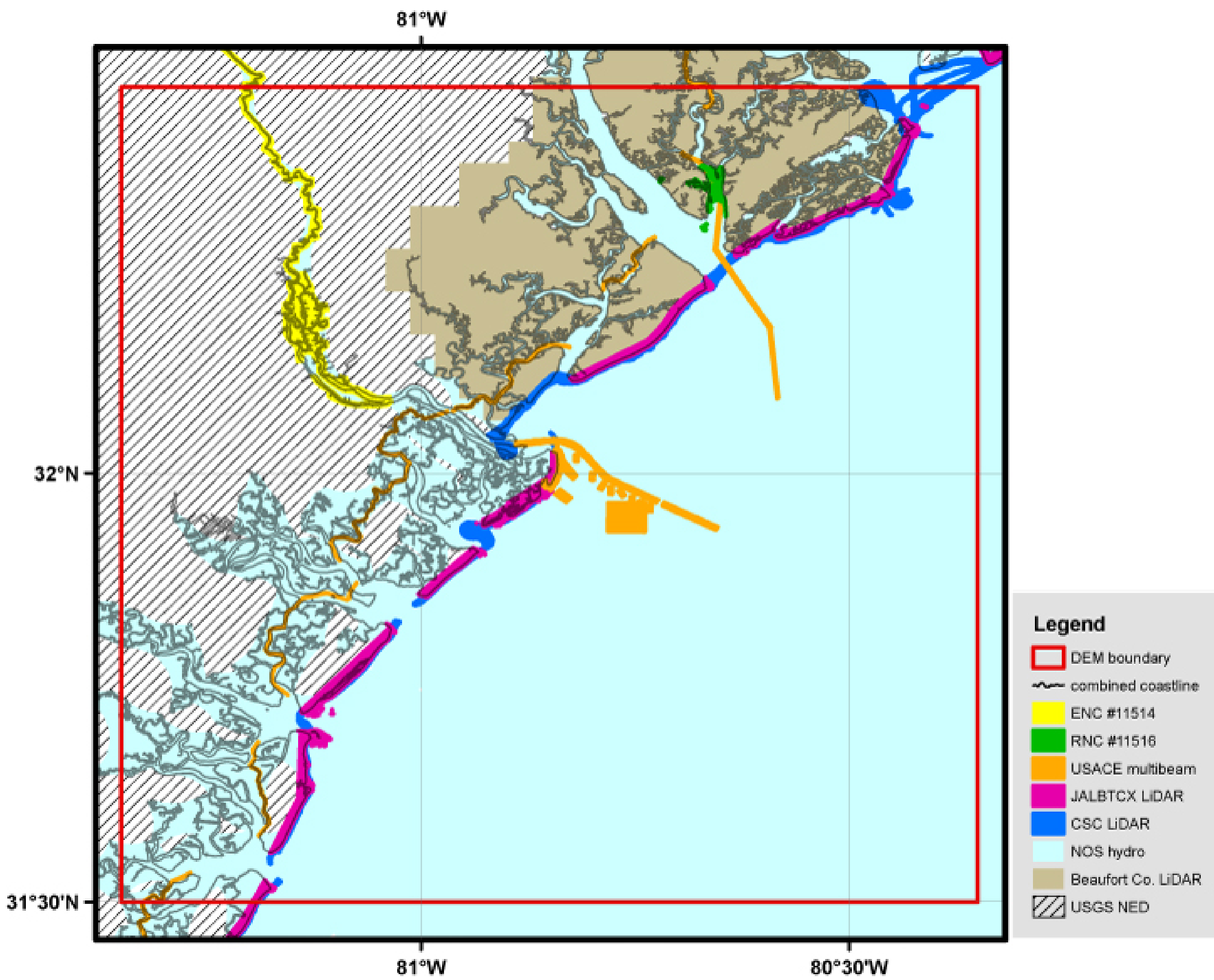

Figure 3. Source and coverage of datasets used to compile the Savannah DEM.

3.1.1 Shoreline

Three digital coastline datasets of the Savannah region were analyzed for inclusion in the Savannah DEM: Office of Coast Survey electronic navigational charts, Coastal Services Center vector shoreline, and Beaufort County, South Carolina digital coastline (Table 2).

Table 2. Shoreline datasets used in compiling the Savannah DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
OCS Electronic Navigational Charts	2006	MHW coastline	Digitized from 1:20,000 and 1:80,000 scale charts	WGS84 geographic	MHW	http://vdatum.noaa.gov/
CSC	1992	MHW coastline	Various	NAD83 geographic	MHW	http://www.csc.noaa.gov/
Beaufort Co.	2002	LiDAR-defined coastline	1 meter	NAD83 State Plane South Carolina, int'l feet	NAVD88	

1) **OCS electronic navigational charts**

Four electronic navigational charts (ENC) were available for the Savannah region (Table 3) and were downloaded from NOAA's Office of Coast Survey (OCS) website (http://vdatum.noaa.gov/); the ENCs are digital versions of NOAA's published nautical charts. The NOAA Coastal Services Center's 'Electronic Navigational Chart Data Handler for ArcView' extension (http://www.csc.noaa.gov/products/enc/) was used to import the data into ArcGIS. The chart data include coastline data files (MHW), which were compared with the other coastline datasets, high-resolution coastal LiDAR data, topographic data, and NOS hydrographic soundings. The ENCs also include soundings (extracted from NOS hydrographic surveys) and land elevations.

The ENC coastline for Charts #11505, 11512, and 11514 generally corresponded well with the high-resolution coastal LiDAR data (near-shore soundings and topography). Manual editing in ESRI ArcMap was required to eliminate piers and docks, and to fit ENC #11505 and #11512 to the JALBCTX Georgia bare earth DEM. The coastline extracted from ENC #11513 was at a lower resolution and did not match other data sets well. It was used only where no other coastline data was available. The ENCs did not provide complete coverage of the Savannah region, and so were used in conjunction with other datasets to build a 'combined coastline' (Fig. 4).

Other NOAA nautical charts in the Savannah area (Table 3) were only available in raster format and were used to evaluate the accuracy and completeness of the coastline datasets.

Table 3. NOAA nautical charts in the Savannah, Georgia region.

RNC #	*Scale*	*Title*	*Edition*	*Edition date*	*ENC available*
11505	1:40,000	SAVANNAH RIVER APPROACH	3rd	2006-08-01	yes
11507	1:40,000	BEAUFORT RIVER TO ST SIMONS SOUND SIDE	32nd	2004-12-01	no
11509	1:80,000	TYBEE ISLAND TO DOBOY SOUND	29th	2005-08-01	no
11510	1:40,000	SAPELO AND DOBOY SOUNDS	19th	2004-05-01	no
11511	1:40,000	OSSABAW AND ST CATHERINES SOUNDS	17th	2004-06-01	no
11512	1:40,000	SAVANNAH RIVER AND WASSAW SOUND	61st	2006-10-01	yes
11513	1:80,000	ST HELENA SOUND TO SAVANNAH RIVER	25th	2006-04-01	yes
11514	1:20,000	SAVANNAH RIVER SAVANNAH TO BRIER CREEK	28th	2005-11-01	yes
11516	1:40,000	PORT ROYAL SOUND AND INLAND PASSAGES	31st	2006-08-01	no
11517	1:40,000	ST HELENA SOUND	17th	2001-08-25	no
11518	1:40,000	INTRACOASTAL WATERWAY CASINO CREEK TO BEAUFORT RIVER	35th	2006-05-01	no
11519	1:40,000	PARTS OF COOSAW AND BROAD RIVERS	12th	2003-04-01	no
11521	1:80,000	CHARLESTON HARBOR AND APPROACHES	28th	2006-02-01	no

2) CSC vector shoreline

NOAA's National Ocean Service (NOS) and National Geodetic Survey (NGS) have developed a high-resolution vector shoreline for parts of the U.S. East Coast. The shoreline is complied from NOS shoreline maps (T-sheets) and CAD-based Standard Digital Data Exchange Format (SDDEF) data.

This shoreline dataset covers both South Carolina and Georgia. It is the primary dataset used in the southwestern portion of the Savannah DEM, as no other high-resolution coastline data was available for this area. Shapefiles were downloaded from the CSC web site and were edited in ArcMap to remove data coverage boundaries. The dataset was consistent with the NOAA raster nautical charts (RNCs), but not recent, high-resolution LiDAR surveys along the coast (e.g., Fig 4). It was therefore edited to match the LiDAR data on the barrier islands in Georgia. Inland areas were edited to match the RNC coastline.

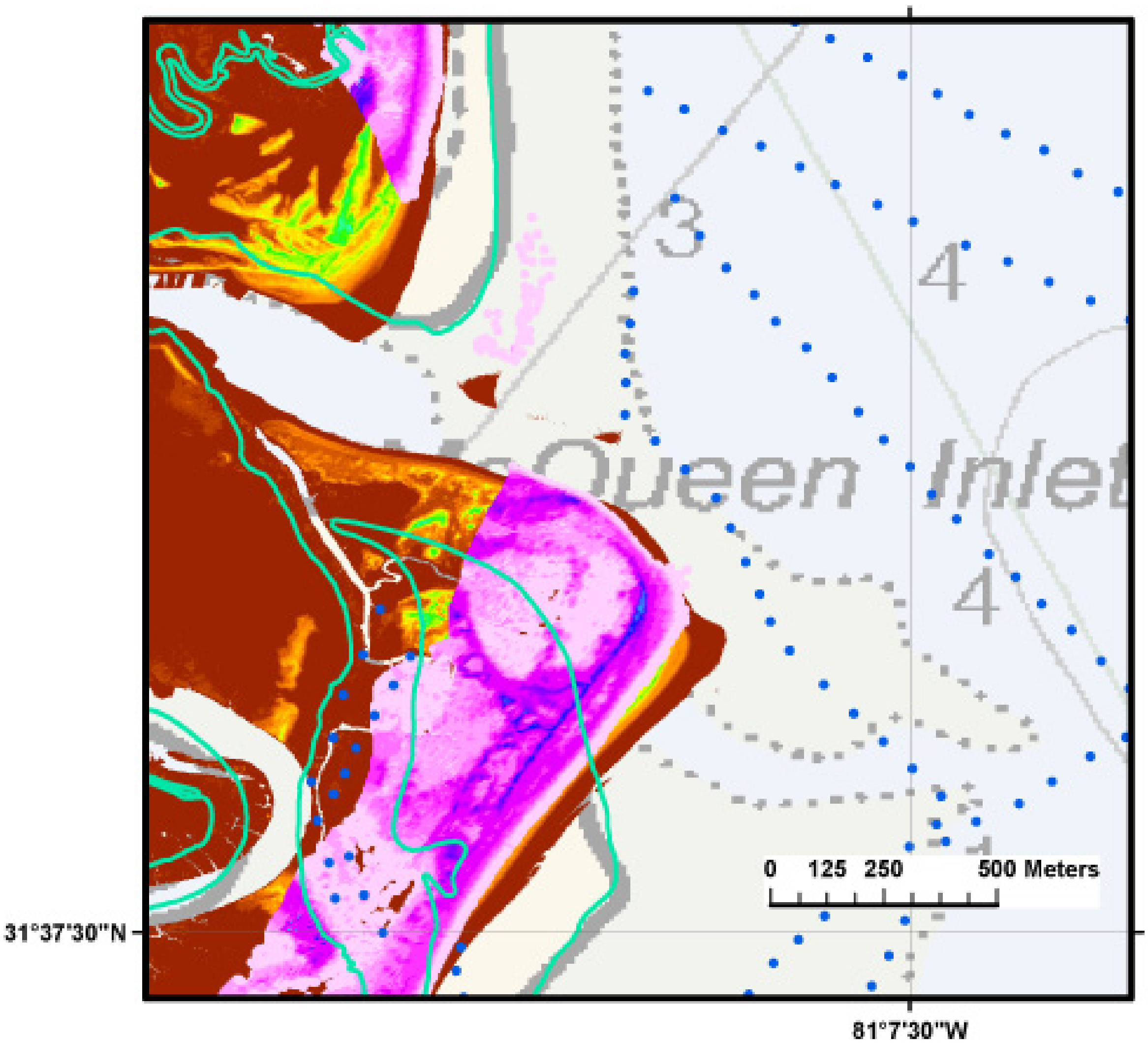

Figure 4. *Coastlines in vicinity of McQueen Inlet, GA. CSC vector shoreline in aqua matches the RNC #11509 depicted coastline. Red-brown is 2006 coastal LiDAR data; purple-blue is 1999 coastal LiDAR data. The CSC coastline was modified to be consistent with the coastal LiDAR data.*

3) Beaufort County shoreline

Beaufort County, South Carolina has produced a topographic dataset using LiDAR data and aerial photography, which was provided to NGDC by Jason Flake of the Beaufort County, South Carolina GIS Department. Within this dataset, a coastline dataset was developed to ensure accurate contouring of point elevation data. This dataset was used in the Savannah DEM as the primary coastline for the northeast portion of the DEM, as the point elevation data was used in that region as well (see Fig. 3). Some editing was necessary to remove extraneous features such as docks and piers, as well as smaller inlets and streams that contained no digital bathymetric data to constrain their depths. The ocean-facing shoreline was edited to match more recent coastal LiDAR data (Fig. 5).

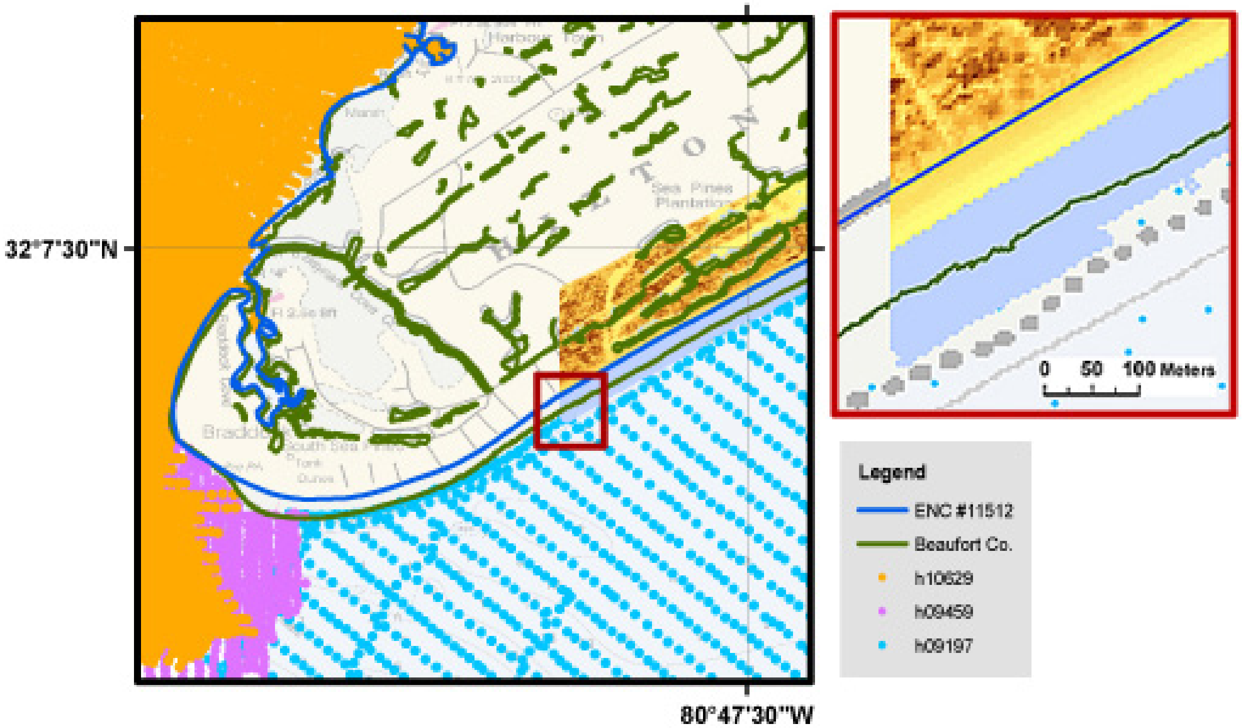

Figure 5. *Coastlines in vicinity of Hilton Head, SC. ENC coastlines and Beaufort County coastline were compared with coastal LiDAR data and NOS hydrographic survey data. Both coastlines differ from the LiDAR by approximately 50m and were shifted to be consistent with the LiDAR data.*

To obtain the best digital MHW coastline, NGDC combined the ENC, CSC and Beaufort County coastlines. Where overlap occurred, this 'combined coastline' (Fig. 6) was manually adjusted in many places, using ArcGIS, to match the high-resolution coastal LiDAR data (e.g., Fig. 5). The combined coastline was converted to point data for use as a coastal buffer for the bathymetric pre-surfacing algorithm (see Section 3.3.4) to ensure that interpolated bathymetric values reached "zero" at the coast. It was also used to clip topographic DEMs, which contained elevation values, typically zero, over rivers and the open ocean (see Section 3.1.3).

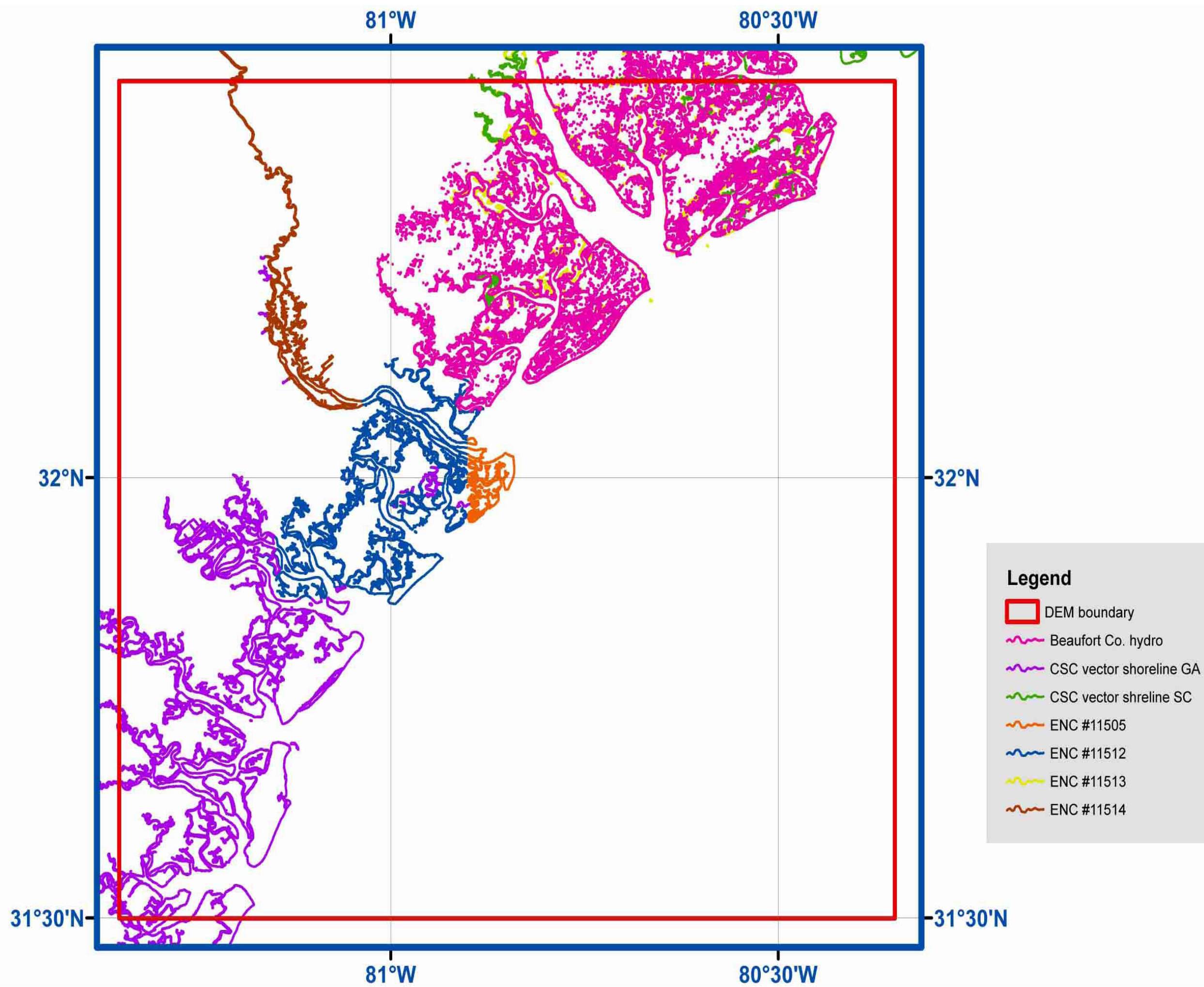

Figure 6. *Digital coastline segments combined for use in the Savannah DEM.*

3.1.2 *Bathymetry*

Bathymetric datasets used in the compilation of the Savannah DEM include 105 NOS hydrographic surveys, 22 USACE surveys of dredged shipping channels, extracted soundings from one ENC, and NGDC-digitized soundings from RNC #11516 (Table 4).

Table 4. Bathymetric datasets used in compiling the Savannah DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1925 to 2005	Hydrographic survey soundings	Ranges from 4 to 400 meters (varies with scale of survey, depth, traffic and probability of obstructions)	NAD27, NAD83	MLW or MLLW (meters)	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
USACE	1960s to 2002	Bathymetric surveys	Ranges from .3 to 15 meters	NAD83 State Plane (GA and SC)	MLW or MLLW (meters)	
OCS ENC #11514	2006	Extracted ENC sounding data	1:20,000	WGS84	MLLW (meters)	http://www.nauticalcharts.noaa.gov/
RNC #11516	2006	Digitized sounding data points	1:40,000	WGS84	soundings in MLLW (feet)	http://www.nauticalcharts.noaa.gov/

1) NOS hydrographic survey data

A total of 105 NOS hydrographic surveys conducted between 1925 and 2005 were utilized in the Savannah DEM development (Fig. 7; Table 5). The hydrographic survey data were originally vertically referenced to either Mean Lower Low Water (MLLW) or Mean Low Water (MLW) and horizontally referenced to either NAD27 or NAD83 datums.

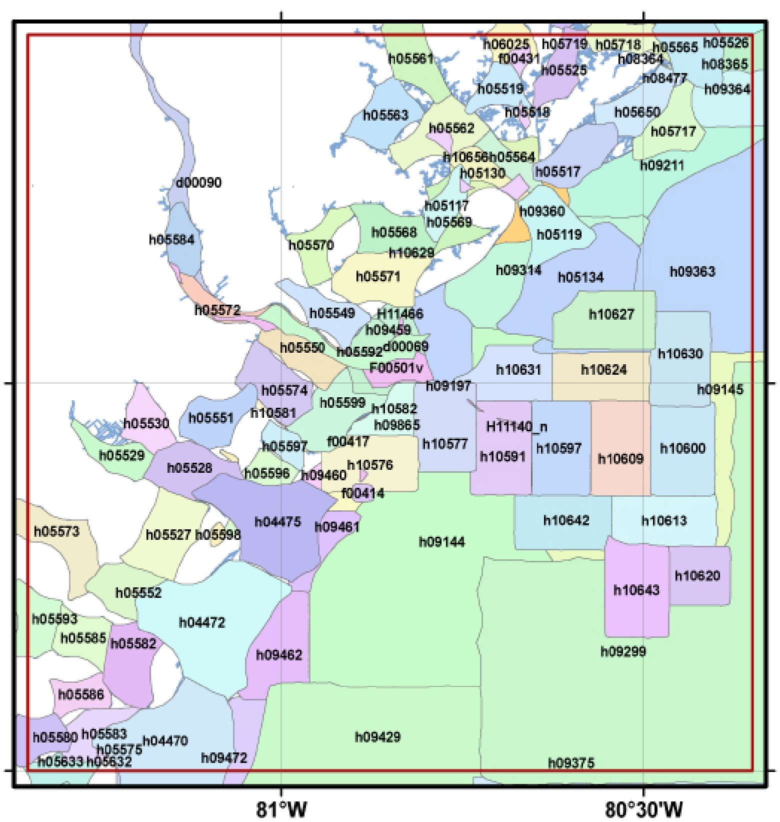

Figure 7. *Digital NOS hydrographic survey coverage in the Savannah region. Red denotes boundary of Savannah DEM.*

Table 5. Digital NOS hydrographic surveys used in compiling the Savannah DEM.

NOS Survey ID	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum*
D00069	1982/83	40,000	mean lower low water	NAD27
D00090*	1982/83	20,000	mean lower low water	NAD27
F00414	1995	10,000	mean lower low water	NAD83
F00417	1995	10,000	mean lower low water	NAD83
F00431	1997	10,000	mean lower low water	NAD83
F00501	2005	10,000	mean lower low water	NAD83
H04470	1925	20,000	mean low water	NAD1913
H04472	1925	20,000	mean low water	NAD1913
H04475	1925	20,000	mean lower low water	NAD27
H05117	1931	10,000	mean low water	NAD27
H05119	1931	20,000	mean low water	NAD27
H05130	1931	10,000	mean low water	NAD27
H05134	1931	40,000	mean low water	NAD27
H05517	1934	10,000	mean low water	NAD27
H05518	1933/34	10,000	mean low water	NAD27
H05519	1933	10,000	mean low water	NAD27
H05520	1934	10,000	mean low water	NAD27
H05525	1934	10,000	mean low water	NAD27
H05526	1934	10,000	mean low water	NAD27
H05527	1934	10,000	mean low water	NAD27
H05528	1934	10,000	mean low water	NAD27
H05529	1934	10,000	mean low water	NAD27
H05530	1934	10,000	mean low water	NAD27
H05549	1934	10,000	mean low water	NAD27
H05550	1934	10,000	mean low water	NAD27
H05551	1934	10,000	mean low water	NAD27
H05552	1934	10,000	mean low water	NAD27
H05560	1934	10,000	mean low water	NAD27
H05561	1934	10,000	mean low water	NAD27
H05562	1934	10,000	mean low water	NAD27
H05563	1934	10,000	mean low water	NAD27
H05564	1934	10,000	mean low water	NAD27
H05565	1934	10,000	mean low water	NAD27
H05568	1934	10,000	mean low water	NAD27
H05569	1934	10,000	mean low water	NAD27
H05570	1934	10,000	mean low water	NAD27
H05571	1934	10,000	mean low water	NAD27
H05572	1934	10,000	mean low water	NAD27
H05573	1934	10,000	mean low water	NAD27
H05574	1934	10,000	mean low water	NAD27
H05575	1934	10,000	mean low water	NAD27
H05580	1934	10,000	mean low water	NAD27
H05582	1934	10,000	mean low water	NAD27
H05583	1934	10,000	mean low water	NAD27
H05584	1934	10,000	mean low water	NAD27
H05585	1934	10,000	mean low water	NAD27
H05586	1934	10,000	mean low water	NAD27
H05592	1934	10,000	mean low water	NAD27
H05593	1934	10,000	mean low water	NAD27
H05596	1934	10,000	mean low water	NAD27
H05597	1934	10,000	mean low water	NAD27
H05598	1934	10,000	mean low water	NAD27
H05599	1934	20,000	mean low water	NAD27

H05632	1934	10,000	mean low water	NAD27
H05633	1934	10,000	mean low water	NAD27
H05650	1934	10,000	mean low water	NAD27
H05654	1934	20,000	mean low water	NAD27
H05717	1934	10,000	mean low water	NAD27
H05718	1934	10,000	mean low water	NAD27
H05719	1934	10,000	mean low water	NAD27
H05721	1934	10,000	mean low water	NAD27
H06025	1934	10,000	mean low water	NAD27
H08364	1956	10,000	mean low water	NAD27
H08365	1957	12,500	mean low water	NAD27
H08477	1957	10,000	mean low water	NAD27
H09144	1973/74	40,000	mean low water	NAD27
H09145	1972/73	40,000	mean low water	NAD27
H09197	1971/73	20,000	mean low water	NAD27
H09198	1971/72	40,000	mean low water	NAD27
H09211	1973	20,000	mean low water	NAD27
H09299	1972	80,000	mean low water	NAD27
H09314	1973	20,000	mean low water	NAD27
H09360	1974	10,000	mean low water	NAD27
H09363	1973	20,000	mean low water	NAD27
H09364	1973	20,000	mean low water	NAD27
H09375	1974	80,000	mean low water	NAD27
H09429	1974	40,000	mean low water	NAD27
H09459	1974	10,000	mean low water	NAD27
H09460	1974	20,000	mean low water	NAD27
H09461	1974	20,000	mean low water	NAD27
H09462	1974	20,000	mean low water	NAD27
H09472	1974	20,000	mean low water	NAD27
H09865	1980	20,000	mean lower low water	NAD27
H10576	1994	10,000	mean lower low water	NAD83
H10577	1994	10,000	mean lower low water	NAD83
H10581	1994/95	10,000	mean lower low water	NAD83
H10582	1994/95	10,000	mean lower low water	NAD83
H10591	1995	10,000	mean lower low water	NAD83
H10597	1995	10,000	mean lower low water	NAD83
H10600	1995	10,000	mean lower low water	NAD83
H10609	1995	10,000	mean lower low water	NAD83
H10613	1995	10,000	mean lower low water	NAD83
H10620	1995	10,000	mean lower low water	NAD83
H10624	1995	10,000	mean lower low water	NAD83
H10627	1995	10,000	mean lower low water	NAD83
H10629	1995	10,000	mean lower low water	NAD83
H10630	1995	10,000	mean lower low water	NAD83
H10631	1995	10,000	mean lower low water	NAD83
H10642	1995	10,000	mean lower low water	NAD83
H10643	1995	10,000	mean lower low water	NAD83
H10656	1995	10,000	mean lower low water	NAD83
H11140	2002	10,000	mean lower low water	NAD83
H11145	2002	10,000	mean lower low water	NAD83
H11466	2005	10,000	mean lower low water	NAD83

* Survey D00090 was not used as the point data were inconsistent with RNC #11514. ENC soundings were used in place of this survey.

Data point spacing for the NOS surveys varied by collection date. In general, earlier surveys had greater point spacing than more recent surveys. All surveys were extracted from NGDC's online database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) in their original datums (Table 5). The data were then converted to WGS84 using FME software, an integrated collection of spatial extract, transform, and load tools for data transformation (http://www.safe.com). The surveys were subsequently clipped to a polygon 0.05 degrees (~5%) larger than the 1/3 arc-second gridding area to support data interpolation along grid edges.

After converting all NOS survey data to MHW (see Section 3.2.1), the data were displayed in ESRI ArcMap and reviewed for digitizing errors against scanned original survey smooth sheets and compared to the USACE multibeam and coastal LiDAR data, NED topographic data, the combined coastline, RNCs, and *Google Earth* satellite imagery. All NOS surveys were manually checked for digitizing errors or erroneous data points using ArcMap. Because the coastline has changed considerably in the past century, the position of many of the inland NOS survey data points had to be adjusted manually to be consistent with the modern 'river' coastline.

Analysis of surfaced NOS data showed two discrepancies between survey data and NOAA nautical chart data. First, in Fripp Inlet, SC older NOS survey data (H05717) did not correspond to more recent raster chart data: a depression in the survey data did not appear on the chart #11517 (Fig. 8), which instead noted an obstruction. In researching an associated depth for the "obstruction fish haven" the feature was found to be non-existent. This information was provided by Robert Martore of the Office of Fisheries Management, Marine Resource Division, South Carolina Department of Natural Resources.

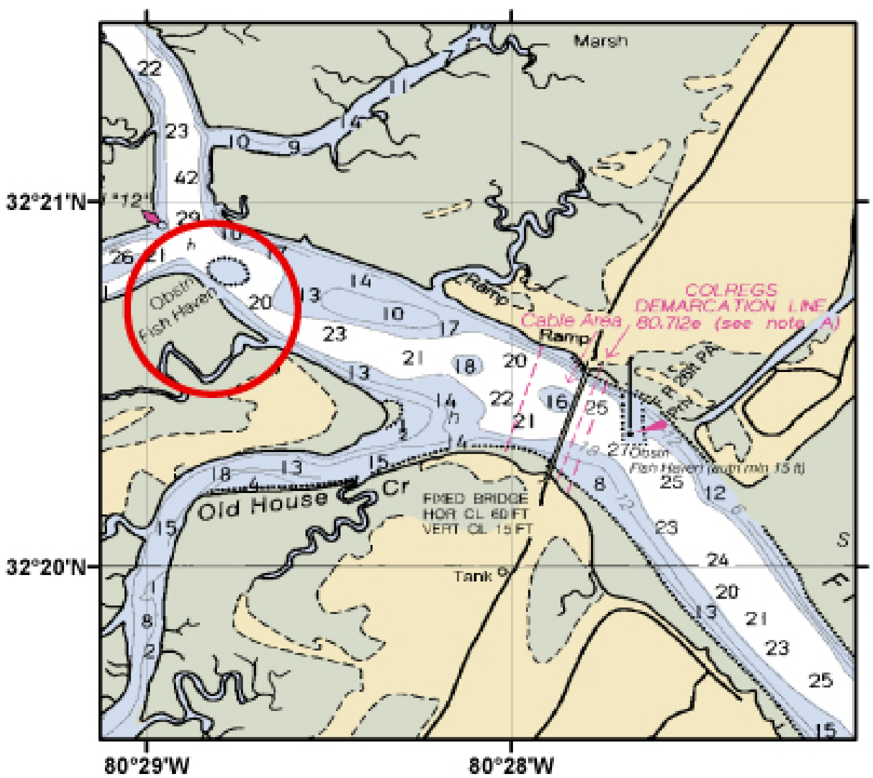

Figure 8. *Nautical Chart #11517 showing non-existent obstruction in Fripp Inlet.*

Secondly, one recent NOS hydrographic survey, H11502, contained soundings that were up to 10 meters shallower than other survey soundings in the same region. The metadata for the survey identified the units as feet and a vertical datum of NAVD88; NOS surveys are always reported in either MLW or MLLW. The metadata was assumed to be incorrect: taking the units to be meters instead of feet produced more consistent soundings. As other survey data covered the specific region completely (Fig. 9), and the metadata was determined to be incorrect, survey #H11502 was not used in the DEM.

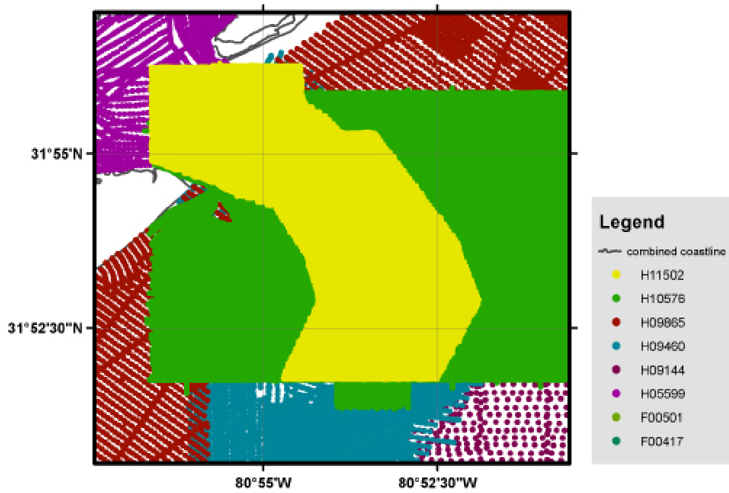

Figure 9. *Hydrographic survey coverage for H11502 (yellow), which was not used in the Savannah DEM.*

2) USACE surveys of dredged shipping channels and the Intracoastal Waterway

The USACE Hydrographic Surveys Division of the Savannah and Charleston Districts provided NGDC with recent survey data in dredged shipping channels (Savannah River and Port Royal Sound) and the Atlantic Intracoastal Waterway (Fig. 10). All data were originally in NAD83 State Plane coordinates (Georgia or South Carolina), and in either MLW or MLLW vertical datum (Table 6).

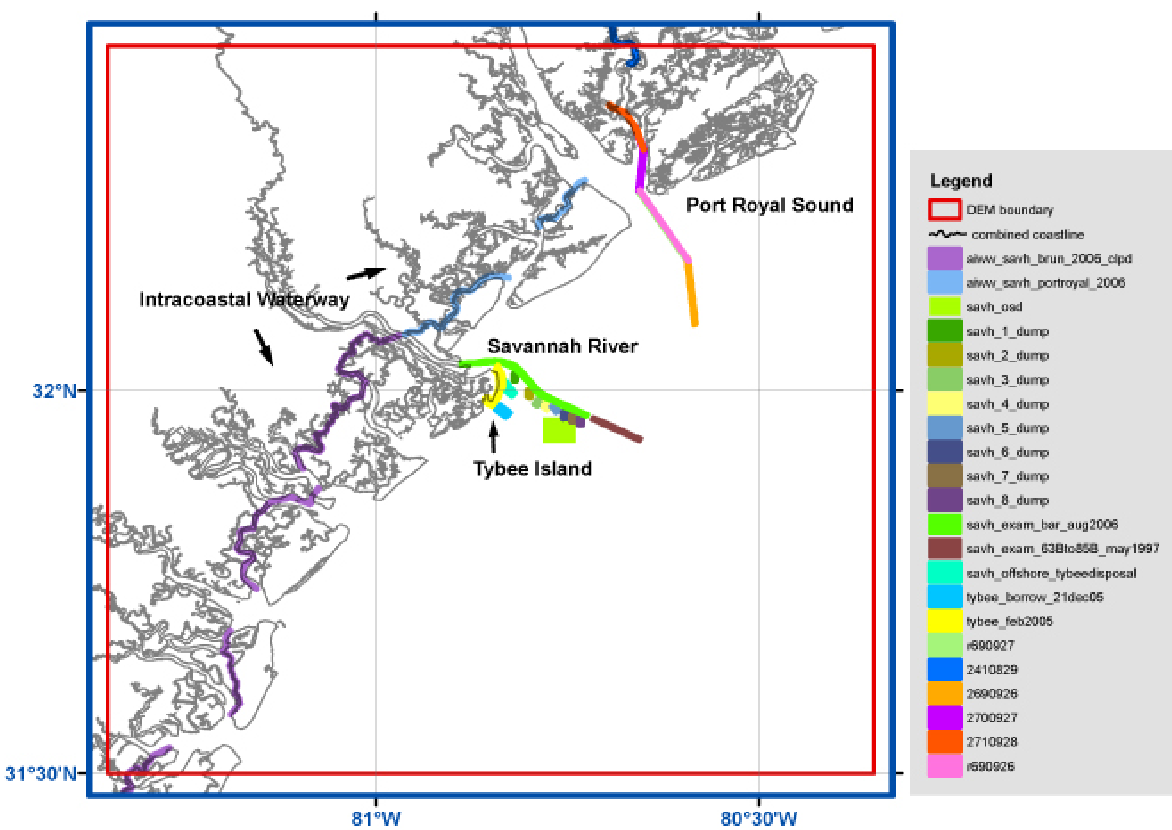

Figure 10. *Location of USACE survey data within dredged shipping channels and the Atlantic Intracoastal Waterway.*

Table 6. USACE survey data within dredged channels and the Atlantic Intracoastal Waterway.

Region	*File name*	*Original horizontal datum*	*Original vertical datum*	*Spatial Resolution*
Port Royal Sound	2690926	NAD83 South Carolina State Plane	MLW	4 parallel survey lines spaced ~40m apart with < 1m point spacing along track
	2700927	NAD83 South Carolina State Plane	MLW	3 parallel survey lines spaced 30m and 50m apart at the northern end and continuing south 4 parallel survey lines spaced ~30m to ~50m at southern most end; point spacing along track <1m
	2710928	NAD83 South Carolina State Plane	MLW	4 parallel survey lines ~50m spacing at northern most end and ~25m continuing southeast ending in single track; all in track point spacing averaging <1m
	r690926	NAD83 South Carolina State Plane	MLW	single survey line with ~1m point spacing
	r690927	NAD83 South Carolina State Plane	MLW	3 parallel survey lines spaced 40m and 60m apart with < 1m point spacing in track
Intracoastal Waterway	aiww_savh_brun_2006	NAD83 Georgia State Plane, eastern zone	MLLW	single along channel survey line < 1m spacing
	aiww_savh_portroyal_2006	NAD83 Georgia State Plane, eastern zone	MLLW	3 parallel survey lines along channel ~20m spacing with < 10m point spacing in track
	2410829	NAD83 South Carolina State Plane	MLW	2 parallel survey lines ~25m spacing with <.5m point spacing in track
Savannah River	savh_1_dump, savh_2_dump, savh_3_dump, savh_4_dump, savh_5_dump, and savh_6_dump	NAD83 Georgia State Plane, eastern zone	MLLW	~450m by 975m block of 9 parallel track lines ~50m spacing and < 1m point spacing in track
	savh_7_dump	NAD83 Georgia State Plane, eastern zone	MLLW	2 blocks ~450m by ~975m one of 14 parallel track lines and the other of 15 track lines ~30m spacing with < 1m point spacing in track
	savh_8_dump	NAD83 Georgia State Plane, eastern zone	MLLW	1 block ~450m by ~975m of 15 parallel track lines ~30m spacing with < 1m point spacing in track
	savh_exam_63Bto85B_may1997	NAD83 Georgia State Plane, eastern zone	MLW	set of channel profiles ~450m wide and spaced ~150m apart with ~5m point spacing
	savh_exam_bar_aug2006	NAD83 Georgia State Plane, eastern zone	MLLW	set of channel profiles ~450m wide and spaced ~150m apart with < 1m point spacing
	savh_osd	NAD83 Georgia State Plane, eastern zone	MLLW	1 block ~4150m by ~3800m of parallel track lines ~150m spacing with ~ 10m point spacing in track
Tybee Island	tybee_borrow_21dec05	NAD83 Georgia State Plane, eastern zone	MLLW	1 block ~850m by ~1650m of 12 parallel track lines spaced ~80m apart with < 1m point spacing in track
	tybee_feb2005	NAD83 Georgia State Plane, eastern zone	MLLW	profile track lines surrounding Tybee I. spacing from 35m to 275m apart with < 1m point spacing in track
	savh_offshore_tybeedisposal	NAD83 Georgia State Plane, eastern zone	MLLW	grouping of tracklines ~ 30m apart with ~10 point spacing in track

3) OCS Nautical Chart Soundings

Digital soundings from ENC #11514 (Fig. 11) were used to augment the NOS hydrographic survey data in the upper reaches of the Savannah River, as NOS survey D00090 was inconsistent with the RNC version of the chart and the modern coastline; D00090 was not utilized in developing the Savannah DEM. There were also no digital NOS hydrographic data available for part of the Beaufort River (Fig. 12). NGDC hand digitized soundings in this region from RNC #11516 to fill the gap between NOS surveys.

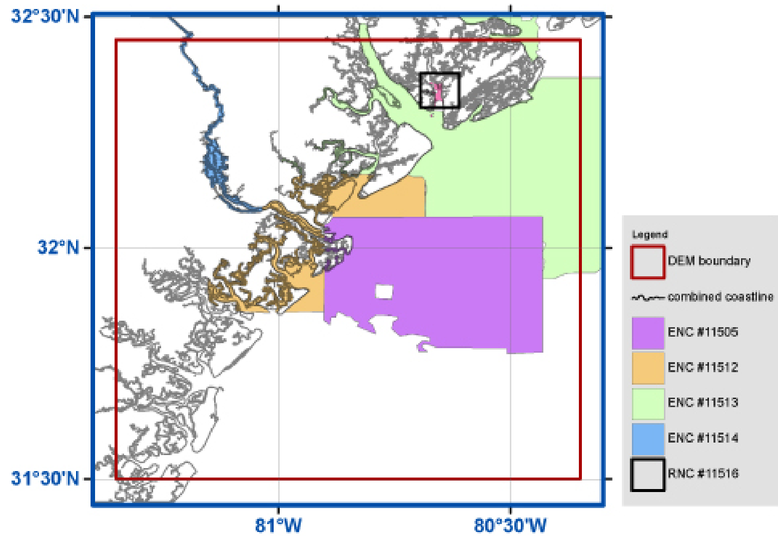

Figure 11. *Coverage of ENC datasets in the Savannah region. ENC #11514 was used in the Savannah DEM, as were some hand digitized soundings from RNC #111516.*

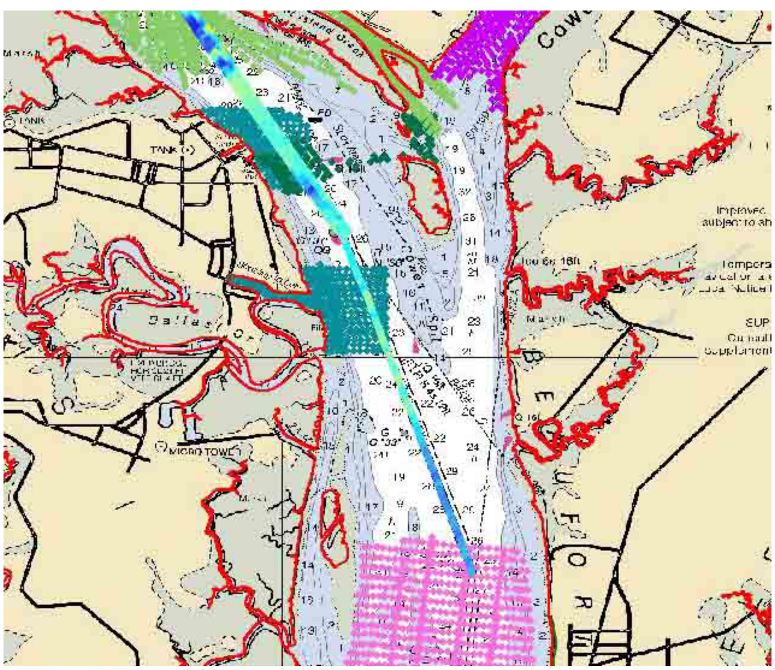

Figure 12. *Non-digital depths in Beaufort River. RNC #11516 (background image) with NOS hydrographic survey data shown in pink and green, illustrate the gap in bathymetric data within Beaufort River. The gap in digital sounding data was filled by hand digitizing soundings on chart #11516.*

3.1.3 Topography

Topographic datasets in the Savannah region were obtained from Chatham County, Georgia, Beaufort County, South Carolina, the U.S. Geological Survey, and NOAA Coastal Services Center (Table 7).

Table 7. Topographic datasets used in compiling the Savannah DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
Beaufort County, SC	2002	LiDAR	~1.25 meter	South Carolina State Plane (intl. feet)	NAVD88 (feet)	
USGS NED	2006	Topographic DEM	1 arc-second DEM	NAD83 geographic	NGVD29 (meters)	http://ned.usgs.gov/
CSC	1997–2000	LiDAR	5-meter point spacing	NAD83 geographic	NAVD88 (meters)	http://maps.csc.noaa.gov/TCM/

1) Chatham County topographic DEM

Chatham County, Georgia has developed a 'hydrologically-correct' topographic DEM of the entire county and surrounding areas, combining LiDAR data and USGS NED topography (for areas not covered by LiDAR). An airborne LiDAR survey was conducted in 1999 to generate countywide 1-foot contours. The data was then used to generate a DEM with 15-foot cell size, which was modified to be consistent with known hydrologic flow in Chatham County. The Chatham County DEM—Georgia State Plane (feet) and NAVD88 (feet) datums—was provided to NGDC by William Brooks of NOAA's Coastal Services Center.

The Chatham County DEM was clipped to the county line, and then to the combined coastline. NGDC's analysis of the clipped DEM revealed many north–south and east–west artifacts that appear to have been introduced during the development of the initial DEM (Fig. 13). The artifacts are expressed as meter-high offsets, and are interpreted as mismatches between the LiDAR and NED topographic data. NGDC could not eliminate these offsets, and as the offsets would significantly affect modeling of coastal flooding, this dataset was not used in building the Savannah DEM.

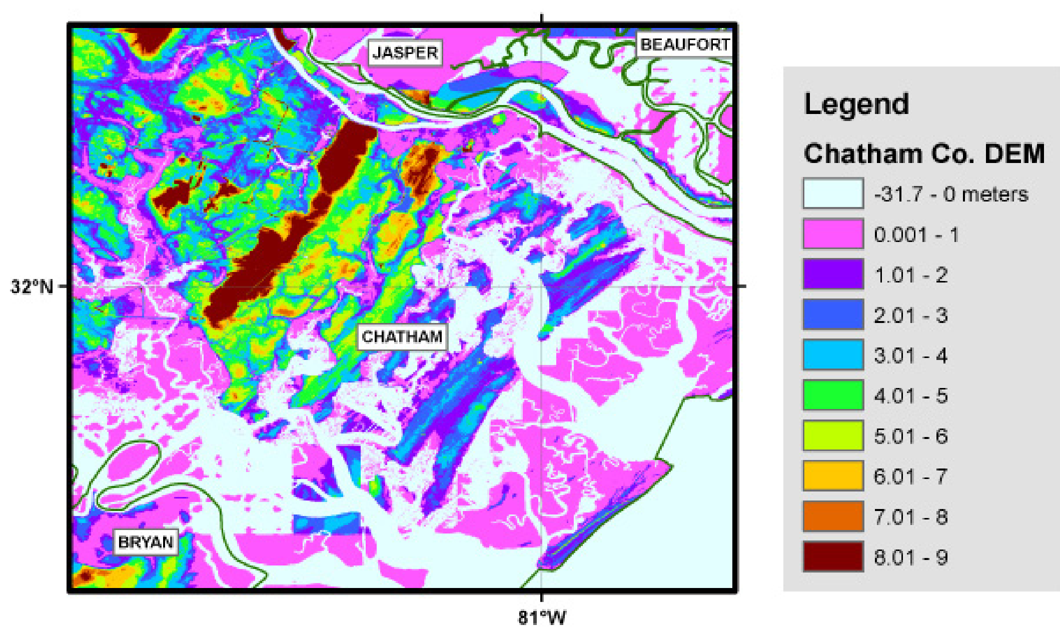

Figure 13. *Color image of part of the Chatham County DEM. The north–south and east–west artifacts are meter-high offsets within the DEM, and are inferred to represent mismatches between the LiDAR and NED topographic data used by the county to build the DEM. This dataset was ultimately deemed inappropriate for coastal inundation modeling.*

2) Beaufort County LiDAR topography

In 2002, Beaufort County, South Carolina funded a LiDAR survey, at 1-foot spacing, of the entire county for storm-water management purposes[2]. Data from the survey were provided to NGDC by Jason Flake of the Beaufort County GIS Department. Data were in South Carolina State Plane coordinates (NAD83, international feet), and NAVD88 vertical datum (feet) and were provided as 245 separate coverage tiles, each containing up to 5 million elevation points—for a total of 742 million points in the Savannah DEM area. The data were processed to "bare earth", and reduced to ~1.25-meter point spacing (4 feet), though there are numerous gaps on the order of 5 to 10 meters throughout the dataset. The dataset also contains values from the surface of water bodies.

NGDC transformed this massive dataset to WGS84 and MHW datums, and to ArcGIS shapefiles, which were subsequently clipped to a boundary 5% larger than the Savannah DEM. The remaining point data were then 'surfaced' to a 1/3 arc-second (~10 m cell-size) raster (see Section 3.3.2). Surfacing permitted clipping of the dataset to the combined coastline, which excised water-surface returns from the open ocean and rivers where NOS hydrographic survey data was available. Noticeable in the original dataset, though subtler in the smoothed 1/3 arc-second surface, are northwest–southeast trending foot-high offsets between what are apparently LiDAR survey tracks (e.g., Fig 14). These artifacts could not be removed and, as this dataset is the best available topographic data for Beaufort County, are therefore present in the Savannah DEM.

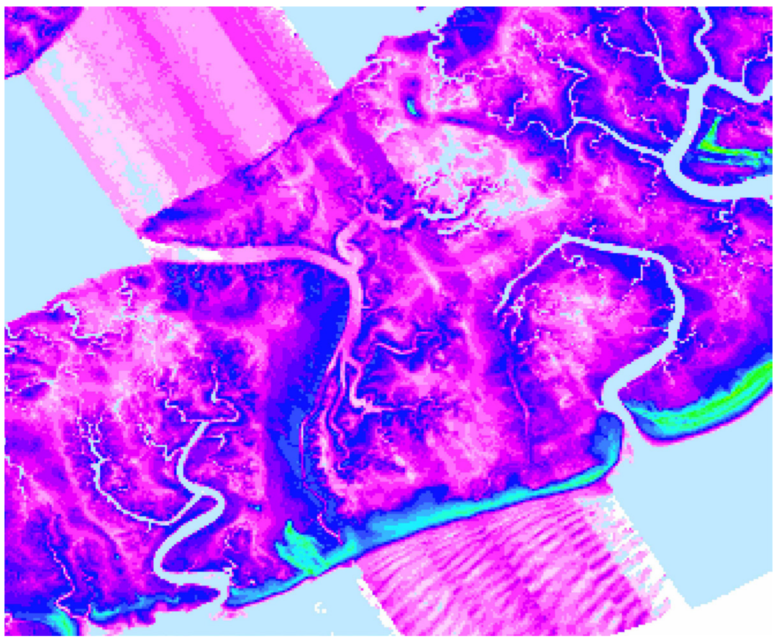

Figure 14. *Color image of part of the 1/3 arc-second surface generated from the Beaufort County LiDAR data. The northwest–southeast trending lineations (foot-high offsets) are inferred to represent the edges of LiDAR survey tracks. Note the "wave" pattern in the bottom portion of the image, caused by LiDAR returns from the surface of the Atlantic Ocean. The water returns were eliminated by clipping to the combined coastline.*

2. With the inception of the Beaufort County Stormwater Utility, the County was tasked with developing detailed county-wide watershed management plans for the primary drainage system, hence the need for accurate 1 foot topography. In 2002, Beaufort County elected to acquire 1 foot county-wide topography derived from LiDAR. Airborne LiDAR mapping is an integration of technologies that enables the capture of accurate topographic data. The technology combines GPS (global positioning system), precision inertial aircraft guidance system, LiDAR (light detection and ranging laser) and computer processing. Basically, a high accuracy scanner sweeps the laser pulses across the flight path (approximately 33,000 pulses per second) and collects the reflected light. The laser range-finder measures the time between sending and receiving each laser pulse to determine the elevation. All the topographic data sets were developed in South Carolina State Plane NAD83, International Feet, and NAVD88. The LiDAR data and the Aerial Photography were developed from a survey control network that was established for the LiDAR project. In order to achieve accurate and consistent results, any data utilized in conjunction with the LiDAR and Aerial Photography must utilize this same control network. The LiDAR coverage area is defined by the County boundary and the 3.75 foot contour for tidally affected areas of Beaufort County. The bare earth points are the foundation data set for the LiDAR derived topographic data for Beaufort County. [Extracted from metadata]

3) USGS NED topography

The U.S. Geological Survey's (USGS) National Elevation Dataset (NED; http://ned.usgs.gov/) provides complete 1 arc-second coverage of the contiguous lower 48 states[3]. Data are in NAD83 geographic coordinates and NAVD88 vertical datum (meters), and are available for download as raster DEMs. The extracted bare-earth elevations have a vertical accuracy of +/- 7 to 15 meters depending on source data resolution. See the USGS Seamless web site for specific source information (http://seamless.usgs.gov/). The dataset was derived from USGS quad maps and aerial photos based on surveys conducted in the 1970s and 1980s.

The NED data included "zero" elevation values over the open ocean (Fig. 15), which were removed from the dataset before gridding. Some anomalous values still remained over the open ocean, which were visually inspected and compared with NOAA nautical charts, the combined coastline, and *Google Earth* satellite imagery. These points were removed in ESRI ArcCatalog by clipping to the combined coastline.

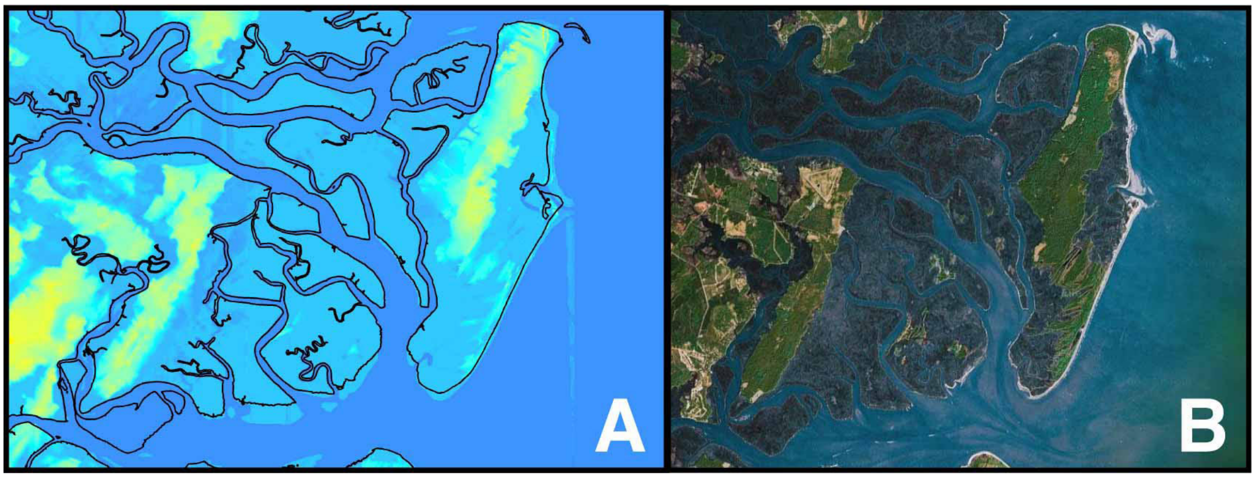

Figure 15. *Color image of the NED DEM in the vicinity of St. Catherine's Island. A) NED DEM. Note mismatch between NED topography, derived from USGS topographic quadrangles, and the combined coastline (black), derived from modern topographic datasets. Data values over the open ocean (dark blue) had to be excised prior to gridding. B) Google Earth satellite image of same region.*

3. The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the maturation of the USGS effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous U.S. and 1:63,360-scale DEM data for Georgia. The dataset provides seamless coverage of the United States, HI, AK, and the island territories. NED has a consistent projection (Geographic), resolution (1 arc second), and elevation units (meters). The horizontal datum is NAD83, except for AK, which is NAD27. The vertical datum is NAVD88, except for AK, which is NGVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc second (10 m) data covers the U.S., then this will also be a seamless dataset. [Extracted from USGS NED website]

4) CSC coastal LiDAR surveys

NOAA Coastal Services Center (CSC) provides online access to coastal topographic LiDAR surveys along the U.S. East Coast. Data in the Savannah region were collected in 1997, 1999, and 2000 with a LiDAR instrument that uses a pulsed laser ranging system mounted onboard an aircraft to measure ground elevation and coastal topography[4]. Coastal LiDAR data in the Savannah region were downloaded from the CSC website (http://www.csc.noaa.gov/lidar/) in NAD83 geographic coordinates (meters) and NAVD88 (meters) at 5-meter point spacing. The LiDAR elevation points are horizontally accurate to +/- 0.8 meters at an aircraft altitude of 700 meters; raw elevation measurements are vertically accurate to within 15 cm. No processing was done by CSC to remove returns from water or vegetation. Thus, data values offshore primarily represent wave features on the ocean surface, not true topography. These data were not processed to bare earth, and thus include man-made structures and vegetation.

Examination of the near-shore data by NGDC indicated that a cutoff of 1 meter below MHW would effectively eliminate most of the open-ocean surface returns while retaining much of the beach-face morphology, as the surveys were generally flown near low tide. Visual inspection of each ESRI shape file after clipping revealed some remaining offshore data points. These points were evaluated in conjunction with NOAA nautical charts and *GoogleEarth* satellite imagery. Many were sea-surface returns and navigation buoys, which were excised.

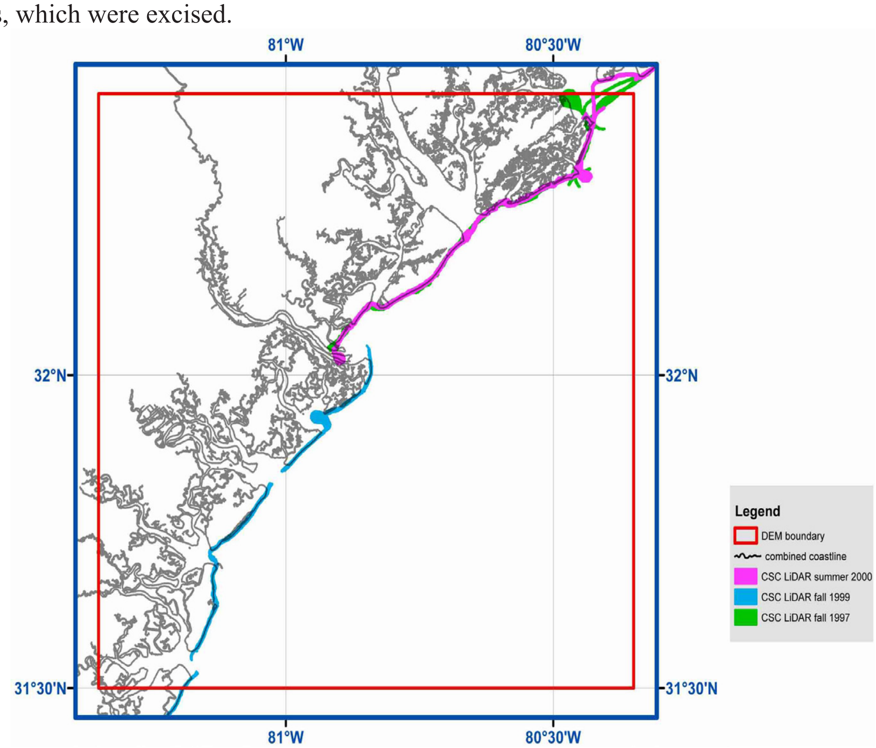

Figure 16. *Coverage of CSC topographic coastal LiDAR data. Data were collected in 1997, 1999, and 2000.*

4. Laser beach mapping uses a pulsed laser ranging system mounted onboard an aircraft to measure ground elevation and coastal topography. The laser emits laser beams at high frequency and is directed downward at the earth's surface through a port opening in the bottom of the aircraft's fuselage. The laser system records the time difference between emission of the laser beam and the reception of the reflected laser signal in the aircraft. The aircraft travels over the beach at approximately 60 meters per second while surveying from the low water line to the landward base of the sand dunes. This data set was collected with a LIDAR (LIght Detection And Ranging) instrument designed and developed by the Observational Sciences Branch (OSB) of NASA at the Wallops Flight Facility in Virginia. The instrument, originally designed for mapping ice sheets in Greenland, is called the Airborne Topographic Mapper or ATM. The ATM II (the latest version), operates with a Spectra Physics laser transmitter, which provides a 7 nanoseconds long, 250 microjoules pulse at a frequency-doubled wavelength of 523 nanometers in the blue-green spectral region. The laser transmitter can function at pulse rates from 2 to 10 kilohertz (kHz). The laser system with a separate cooling unit weighs approximately 45 kilograms (kg) and requires approximately 15 amperes of power at 115 volts. The transmitted laser pulse is reflected to the surface of the earth with the aid of a small folding mirror mounted on the back of a secondary mirror of a rotating scan mirror assembly mounted directly in front of the telescope. The scan mirror, which is rotated at 20 hertz, is comprised of a section of round aluminum stock, machined to a specific off-nadir angle. A scan mirror with the off-nadir angle of 15 degrees was utilized, producing an elliptical scan pattern with a swath width equal to 50 percent of the approximately 700-meter aircraft altitude. The reflected laser pulse is transmitted to a photo-multiplier assembly that consists of a lens, a narrow bandpass filter, and a single photomultiplier tube. [Extracted from metadata]

3.1.4 Topography–Bathymetry

Combined topographic–bathymetric surveys of coastal Georgia and South Carolina (Fig. 17) were performed in 2006 by the Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX; Table 8). The data were collected using the CHARTS (Compact Hydrographic Airborne Rapid Total Survey) system to depict elevations above and below water along the immediate coastal zone[5]. The surveys generally extend 750 meters inland and up to 1500 meters over the water. Data points are spaced approximately every 2 meters, and have an accuracy better than 3.0 meters horizontally and 0.3 meters vertically. These data were not processed to bare earth.

Table 8. Combined topographic–bathymetric datasets used in compiling the Savannah DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*
JALBTCX	2006	Coastal topography and bathymetry	5-meter point data	NAD83 geographic	NAVD88 (meters)

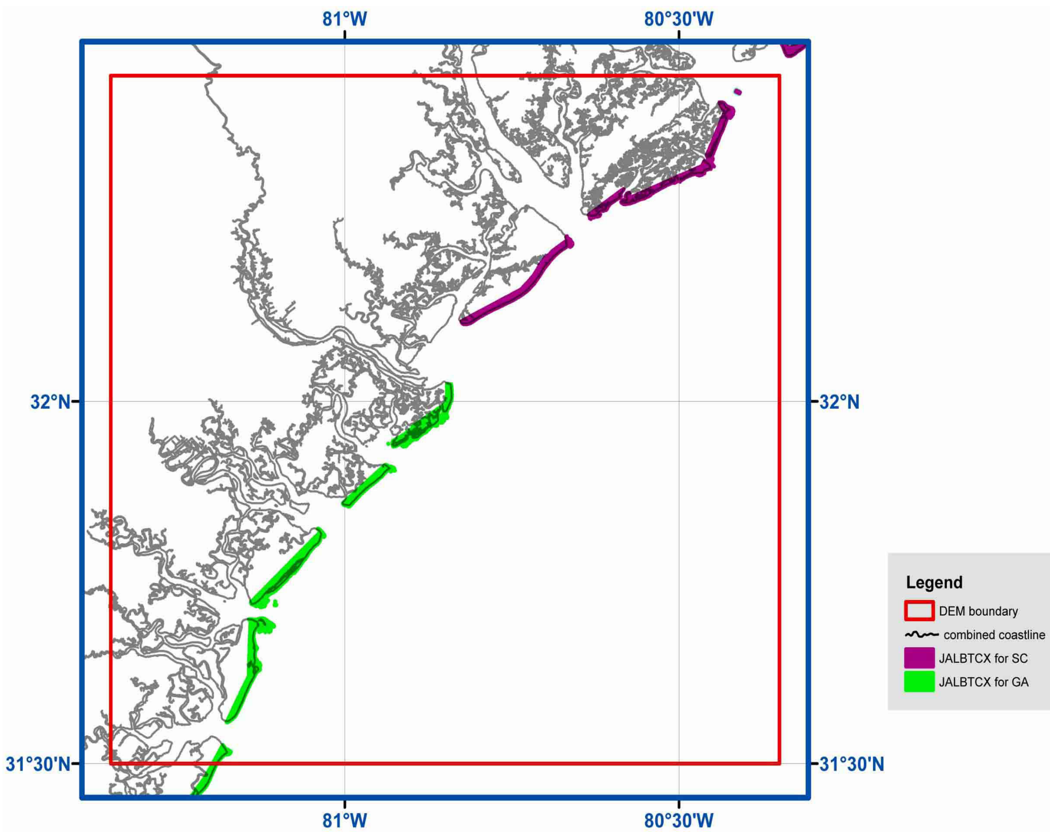

Figure 17. *Spatial coverage of JALBTCX high-resolution (5-meter point spacing) coastal bathymetric–topographic LiDAR surveys in the vicinity of Savannah that were utilized in DEM development.*

5. These data were collected using a SHOALS-1000T system. It is owned and operated by Fugro Pelagos performing contract survey services for the US Army Corps of Engineers. The system collects topographic lidar data at 10kHz and hydrographic data at 1kHz. The system also collects RGB imagery at 1Hz. Aircraft position, velocity and acceleration information are collected through a combination of Novatel and POS A/V equipment. Raw data are collected and transferred to the office for downloading and processing in SHOALS GCS software. GPS data are processed using POSPac software and the results are combined with the lidar data to produce 3-D positions for each lidar shot. These data are edited using Fledermaus software to remove anomalous data from the dataset. The edited data are unloaded from SHOALS GCS, converted from ellipsoid to orthometric heights, based on the GEOID03 model, and split into geographic tiles covering approximately 5km each. [Extracted from metadata]

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Savannah DEM were originally referenced to a number of vertical datums including Mean Lower Low Water (MLLW), Mean Low Water (MLW), National Geodetic Vertical Datum of 1929 (NGVD29) and North American Vertical Datum of 1988 (NAVD88). All datasets were transformed to MHW to provide the worst-case scenario for inundation modeling. Units were converted from feet to meters as appropriate.

1) **Bathymetric data**

   The NOS hydrographic surveys, USACE surveys, and NOAA nautical charts soundings were transformed from MLLW and MLW to MHW, using FME software, by adding a constant offset measured at the NOAA Savannah tidal station (see Table 9).

2) **Topographic data**

   The USGS NED, CSC coastal LiDAR and Beaufort County LiDAR data were originally referenced to NAVD88. Conversion to MHW, using FME software, was accomplished by adding constant offsets per Table 9.

3) **Topographic–bathymetric data**

   Combined topographic–bathymetric coastal LiDAR survey data were transformed from NAVD88 to MHW (Table 9) using FME.

Table 9. Relationship between Mean High Water and other vertical datums in the Savannah region.*

Vertical datum	*Difference to MHW*
NGVD29	-0.660
NAVD88[a]	-0.939
MSL	-1.009
MLW	-2.108
MLLW	-2.174

* Datum relationships determined by tidal station #8670870 at Fort Pulaski, Savannah, Georgia.

3.2.2 Horizontal datum transformations

Datasets used to compile the Savannah DEM were originally referenced to UTM Zone 17, State Plane, NAD83, or WGS84 horizontal datums. The relationships and transformational equations between these horizontal datums are well established. All data were converted to a horizontal datum of WGS84 using FME software.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

After horizontal and vertical transformations were applied, the resulting ESRI shape files were checked in ESRI ArcMap for inter-dataset consistency. Problems and errors were identified and resolved before proceeding with subsequent gridding steps. The evaluated and edited ESRI shape files were then converted to xyz files in preparation for gridding. Problems included:

- Data values over the open ocean and rivers in the NED DEM and Beaufort County LiDAR data. Each dataset required automated clipping to the combined coastline.
- Presence of buildings and other man-made structures, as well as trees, in the coastal LiDAR datasets from CSC and JALBTCX. As these datasets were not bare earth, NGDC eliminated elevations greater than 3 meters above MHW to crudely remove such features while retaining coastal morphology.
- Digital, measured bathymetric values from NOS surveys date back over 70 years. More recent data, such as USACE surveys in dredged shipping channels, differed from older, pre-dredging NOS data by as much as 10 meters. The older NOS survey data were excised where more recent bathymetric data exists.

3.3.2 Averaging of Beaufort County LiDAR data

The massive volume of point data (742 million) in the Beaufort County, South Carolina LiDAR data, as well as their small point-spacing (~1.25 meters) and the fact that the dataset contained returns from the surface of water bodies, necessitated averaging the data to a more manageable 1/3 arc-second spacing. This was accomplished by generating a 'pre-surface' or grid using GMT, an NSF-funded share-ware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

The individual point data were median-averaged using the GMT tool 'blockmedian' onto a 1/3 arc-second grid 0.05 degrees (~5%) larger than Beaufort County, such that the median value of all of the points lying within each 1/3 arc-second cell (~10 by 10 meters) was calculated and output. The GMT tool 'surface' then created a grid or 'surface' of the median-averaged point data. This grid was converted into an ESRI Arc ASCII grid file using the MB-System tool 'mbm_grd2arc'. Conversion of this Arc ASCII grid file into an Arc raster permitted clipping of the grid by the combined coastline (to eliminate data interpolation into areas outside the initial LiDAR data coverage and to remove water returns). The resulting surface was compared with the original soundings to ensure grid accuracy, converted to a shape file, and then exported as an xyz file for use in the final gridding process (see Table 9).

3.3.3 Interpolation of USACE bathymetric data

The USACE hydrographic surveys are more recent than most of the NOS hydrographic surveys that they overlap with, and are considered to be more accurate as they reflect dredging of modern shipping channels and the Atlantic Intracoastal Waterway. Offshore of the Savannah River, the USACE survey data are sparse enough in some places that they were first pre-surfaced with GMT (See Section 3.3.2) to 1 arc-second spacing to fully infill the dredged channel with interpolated depths. This surface was closely cropped to the extents of the USACE surveys, compared with the original survey values, and then used in creating an overall bathymetric 'pre-surface' (see Section 3.3.4).

3.3.4 Smoothing of bathymetric data

The NOS hydrographic surveys are generally sparse at the resolution of the 1/3 arc-second grid: in deep water, the NOS survey data have point spacings up to 400 meters apart. In order to reduce the effect of artifacts in the form of lines of "pimples" in the 1/3 arc-second DEM due to this low resolution dataset, and to provide effective interpolation into the coastal zone, a 1 arc-second-spacing 'pre-surface' or grid was generated using GMT (see Section 3.3.2).

The NOS hydrographic point data, in xyz format, were combined with the interpolated USACE pre-surface, and ENC and NGDC-digitized RNC soundings into a single file, along with points extracted from the combined coastline—to provide a "zero" buffer along the entire coastline. These point data were then median-averaged using the GMT tool 'blockmedian' to create a 1 arc-second grid 0.05 degrees (~5%) larger than the Savannah DEM gridding region. The GMT tool 'surface' then applied a tight spline tension to interpolate cells without data values. The GMT grid created by 'surface' was converted into an ESRI Arc ASCII grid file, and clipped to the combined coastline (to eliminate data interpolation into land areas). The resulting surface was compared with the original soundings to ensure grid accuracy (e.g., Fig. 18), converted to a shape file, and then exported as an xyz file for use in the final gridding process (see Table 10).

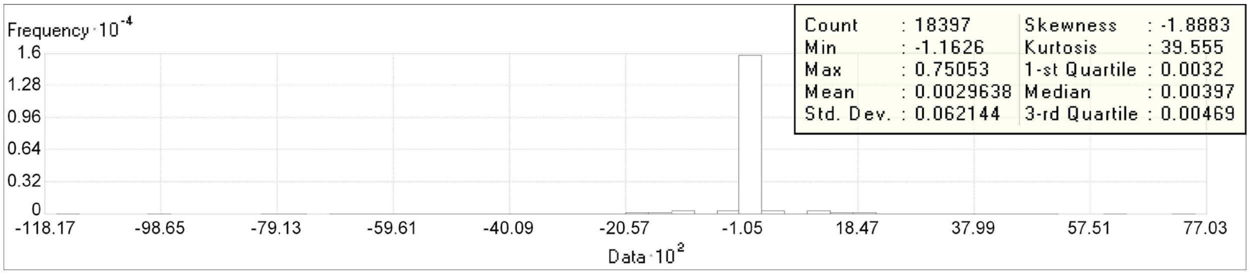

Figure 18. *Histogram of the difference between NOS hydrographic survey H10620 (relatively dense survey in deeper water) and the 1 arc-second pre-surfaced bathymetric grid. Pre-surface cell values are highly consistent with the original hydrographic survey soundings.*

3.3.5 Gridding the data with MB-System

MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/) was used to create the 1/3 arc-second Savannah DEM. MB-System is an NSF-funded share-ware software application specifically designed to manipulate submarine multibeam sonar data, though it can utilize a wide variety of data types, including generic xyz data. The MB-System tool 'mbgrid' applied a tight spline tension to the xyz data, and interpolated values for cells without data. The data hierarchy used in the 'mbgrid' gridding algorithm, as relative gridding weights, is listed in Table 10. Greatest weight was given to the high-resolution NOS multibeam and coastal LiDAR survey data. Least weight was given to the pre-surfaced 1 arc-second NOS bathymetric grid. Gridding was performed in quadrants, each with a 5% data overlap buffer. The resulting Arc ASCII grids were seamlessly merged in ArcCatalog to create the final 1/3 arc-second Savannah DEM.

Table 10. Data hierarchy used to assign gridding weight in MB-System.

Dataset	*Relative Gridding Weight*
USACE bathymetry	100
JALBTCX coastal lidar bathymetry–topography	100
Beaufort County pre-surfaced LiDAR grid	100
CSC coastal lidar topography	10
NOS hydrographic surveys: bathymetric soundings	1
NOAA nautical chart soundings	1
USGS NED topographic DEM	0.01
Pre-surfaced bathymetric grid	0.01

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Savannah DEM is dependent upon the datasets used to determine corresponding DEM cell values. Topographic features have an estimated accuracy of 10 to 15 meters: Beaufort County and coastal LiDAR have an accuracy of between 1 and 3 meters, NED topography is accurate to within about 15 meters. Bathymetric features are resolved only to within a few tens of meters in deep-water areas, in the southeast corner of the DEM. Shallow, near-coastal regions, rivers, and dredged shipping channels have an accuracy approaching that of subaerial topographic features. Positional accuracy is limited by: the sparseness of deep-water and inland river soundings; potentially large positional uncertainty of pre-satellite navigated (e.g., GPS)

NOS hydrographic surveys; and by natural and artificial morphologic change that has occurred since the hydrographic surveys were conducted.

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the Savannah DEM is also highly dependent upon the source datasets contributing to grid cell values. Topographic areas have an estimated vertical accuracy between 0.15 (for Beaufort County and coastal LiDAR data) and up to 7 meters (for NED topography). Bathymetric areas have an estimated accuracy of between 0.1 meters and 5% of water depth (~2 meters in the southeast corner of the DEM). Those values were derived from the wide range of input data sounding measurements from the early 20th century to recent, GPS-navigated sonar surveys. Gridding interpolation to determine values between sparse, poorly-located NOS soundings degrades the vertical accuracy of elevations in deep-water. Also suspect are the accuracy of values within inland rivers, as substantial morphologic change has occurred in some areas since the NOS hydrographic surveys of the 1930s to 1970s.

3.4.3 Slope maps and 3-D perspectives

ESRI ArcCatalog was used to generate a slope grid from the 1/3 arc-second Savannah DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 19). The DEM was transformed to UTM Zone 17 coordinates (horizontal units in meters) in ArcCatalog for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Three-dimensional viewing of the UTM-transformed DEM (e.g., Fig. 20) was accomplished using ESRI ArcScene. Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEM. Figure 21 shows a color image of the 1/3 arc-second Savannah DEM in its final version

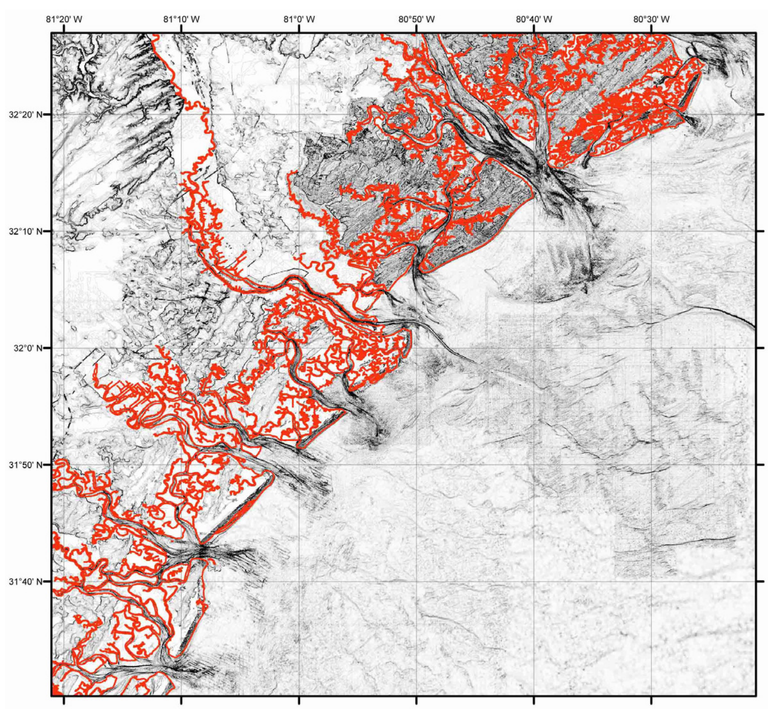

Figure 19. *Slope map of the 1/3 arc-second Savannah DEM. Flat-lying slopes are white; dark shading denotes steep slopes; combined coastline in red.*

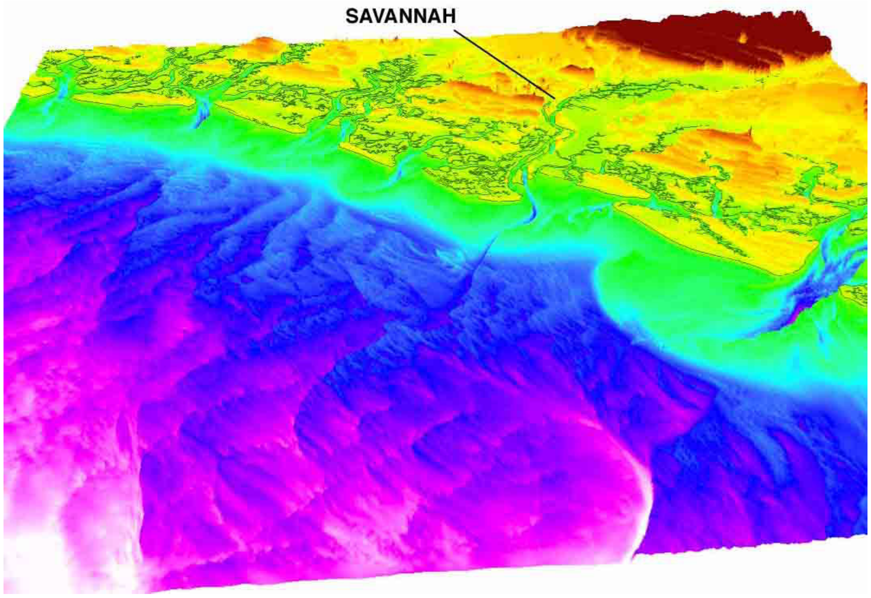

Figure 20. Perspective view from the east of the 1/3 arc-second Savannah DEM. Combined coastline in black; vertical exaggeration–times 100.

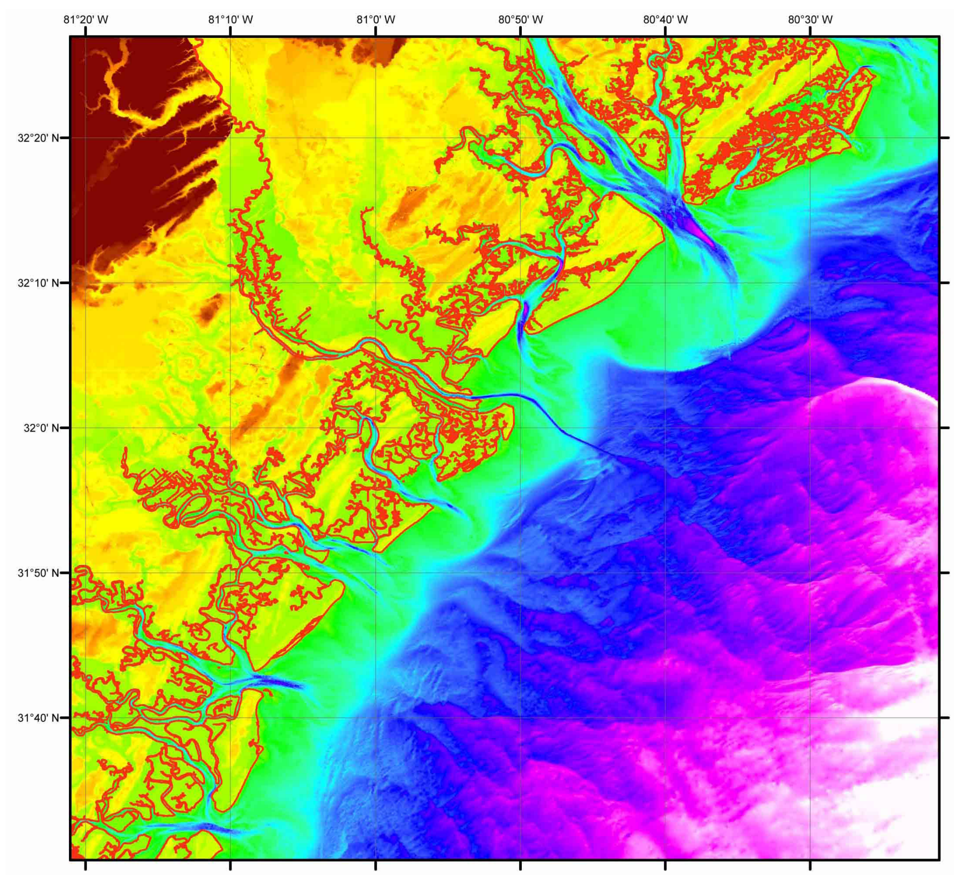

Figure 21. Color image of the Savannah DEM.

3.4.4 Comparison with source data files

To ensure grid accuracy, the Savannah DEM was compared to select source data files. Files were chosen on the basis of their contribution to the grid-cell values in their coverage areas (i.e., had the greatest weight and did not significantly overlap other data files with comparable weight). A histogram of the difference between a JALBTCX coastal bathymetric–topographic LiDAR survey file and the Savannah DEM is shown in Fig. 22.

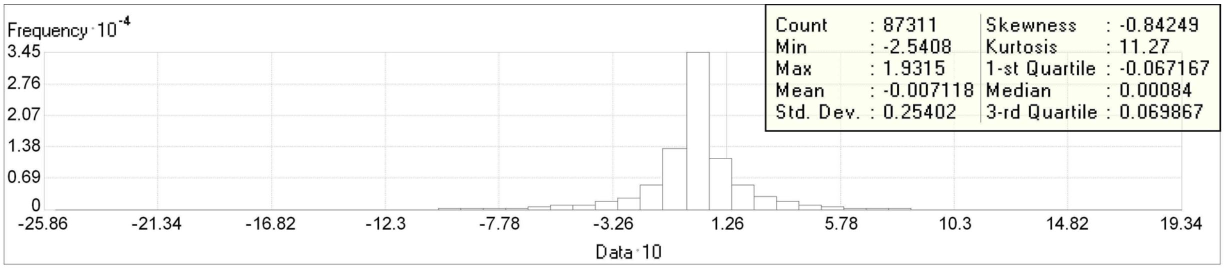

Figure 22. *Histogram of the difference between one file of the JALBTCX coastal bathymetric–topographic LiDAR survey (87,311 points) and the 1/3 arc-second Savannah DEM.*

3.4.5 Comparison with NOAA tidal stations

The National Geodetic Survey (NGS) data sheets for U.S. tidal stations (http://tidesandcurrents.noaa.gov/) document benchmark elevations, in meters above MHW, allowing for direct comparison with DEM values at those locations. There is only one tidal station within the Savannah study area (Fort Pulaksi, Savannah River, Georgia, #8670870), which was compared with the value taken at the same locale from the 1/3 arc-second Savannah DEM (see Fig. 23 and Table 11 for station location). The 1/3 arc-second DEM value of 2.477 meters for that location (Table 11) derives from the 1 arc-second USGS NED topographic DEM and the summer of 2000 CSC coastal topographic LiDAR survey, which was not processed to bare earth. The area has significant vegetation and buildings, which the tide-station bench mark is close to, likely contributing to the observed offset with the DEM.

Table 11. Comparison of NOAA tidal benchmark elevation, in meters above MHW, with the 1/3 arc-second Savannah DEM.

Station number	*Station name*	*Year*	*Longitude*	*Latitude*	*Bench mark*	*DEM*	*Difference*
8670870	Fort Pulaski	1978	80.8947222° W	32.0286111° N	0.723	2.477	1.754

3.4.6 Comparison with NGS geodetic monuments

The elevations of 1169 NOAA NGS geodetic monuments were extracted from online shapefiles of monument datasheets (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl), which give monument positions in NAD83 (sub-mm accuracy) and elevations in NAVD88 (in meters). Elevations were shifted to MHW vertical datum (see Table 9) for comparison with the Savannah DEM (see Fig. 23 for monument locations). Differences between the Savannah DEM and the NGS geodetic monument elevations range from -17 to 7 meters, with a negative value indicating that the DEM is less than the monument elevation (e.g., Fig. 24). Examination of the monuments with the largest positive offsets from the DEM revealed that they are mounted on bridges spanning a river. Those with the largest negative offsets are close to topographic highs that are poorly resolved within the 1 arc-second NED topographic DEM.

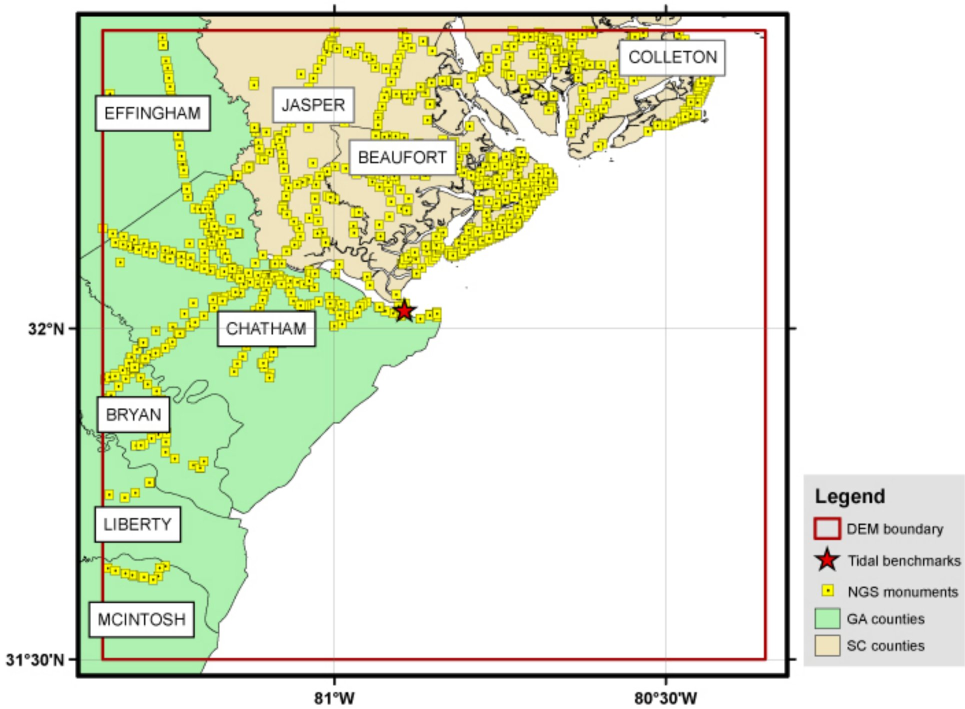

Figure 23. *Location of NGS monuments and NOAA tidal benchmark used for evaluating the Savannah DEM.*

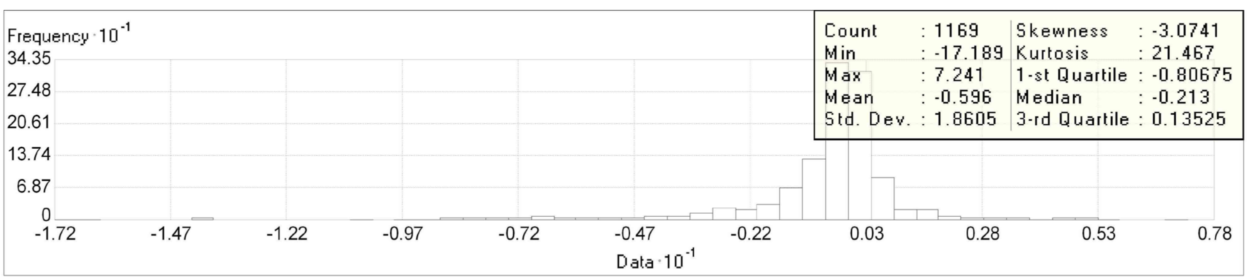

Figure 24. *Histogram of the differences between NGS geodetic monument elevations and the 1/3 arc-second Savannah DEM.*

4. Summary and Conclusions

A topographic–bathymetric digital elevation model of the Savannah, Georgia region, with cell spacing of 1/3 arc-second, was developed for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research. The best available digital data from U.S. federal agencies were obtained by NGDC, shifted to common horizontal and vertical datums, and evaluated and edited before DEM generation. The data were quality checked, processed and gridded using ESRI ArcGIS, FME, GMT, and MB-System software.

Recommendations to improve the Savannah DEM, based on NGDC's research and analysis, are listed below:

- Process coastal LiDAR data to bare earth.
- Obtain digital versions of several NOAA nautical charts (#11507, 11509, 11510, 11511, 11516, 11517, 11518, 11519, and 11521) that have not yet been digitized.
- Improve topography in the regions currently covered by NED 1 arc-second data (in the central and western parts of the DEM). This may be accomplished in part by acquiring the original Chatham County LiDAR data, which was unavailable for this project.

- NOS mapping of inland waterways where significant morphologic change has occurred since the original surveys utilized in this study were conducted.

5. Acknowledgments

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6. References

Nautical Chart #11505, 3rd Edition, 2006. Savannah River Approach. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11507, 32th Edition, 2004. Beaufort River to St. Simons Sound Side. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11509, 29th Edition, 2005. Tybee Island to Dobay Sound. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11510, 19th Edition, 2004. Sapelo and Doboy Sounds. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11511, 17th Edition, 2004. Ossabaw and St. Catherines Sounds. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11512, 61st Edition, 2006. Savannah River and Wassaw Sound. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11513, 25th Edition, 2006. St. Helena Sound to Savannah River. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11514, 28th Edition, 2005. Savannah River Savannah to Brier Creek. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11516, 31st Edition, 2006. Port Royal Sound and Inland Passages. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11517, 17th Edition, 2001. St. Helena Sound. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11518, 35th Edition, 2006. Intracoastal Waterway Casino Creek to Beaufort River. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11519, 12th Edition, 2003. Parts of Coosaw and Broad Rivers. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11521, 28th Edition, 2006. Charleston Harbor and Approaches. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

7. Data Processing Software

ArcGIS v. 9.1, developed and licensed by ESRI, Redlands, California, http://www.esri.com/

Electronic Navigational Chart Data Handler for ArcView, developed by NOAA Coastal Services Center, http://www.csc.noaa.gov/products/enc/

FME 2006 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

GEODAS v. 5 – Geophysical Data System, shareware developed and maintained by Dan Metzger, NOAA National Geophysical Data Center, http://www.ngdc.noaa.gov/mgg/geodas/

GMT v. 4.1.1 – Generic Mapping Tools, shareware developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/

MB-System v. 5.0.9, shareware developed and maintained by David W. Caress and Dale N. Chayes, funded by the National Science Foundation, http://www.ldeo.columbia.edu/res/pi/MB-System/